power and the controller is in boost mode. Region 3 occurs when the wind turbine is producing power but the controller is not in boost mode. Region 4 occurs when the wind speed is higher than the rated wind speed and the controller puts the wind turbine into stall mode.

Region 1 is when the wind is too low for power production. The range of Region 1 varies depending on the details of the wind turbine design. For the preferred embodiment, Region 1 occurs when the wind turbine rotor is below approximately 500 RPM. This corresponds to a wind speed below approximately 7 mph. When the wind turbine is in Region 1, the controller is not in boost mode and the duty cycle of the FETs is 0%.

Region 2 is when the wind turbine has begun producing power and boost mode is employed to achieve the desired output voltage and to improve the wind turbine's starting characteristics. In Region 2, the duty cycle is defined by the following equation:

$$DC = (C1 * V + C2) * RPM + C3 * V + C4 \qquad \text{Equation 1}$$

where DC represents the duty cycle expressed as a percentage, V is the battery voltage as measured by the voltage sensor, RPM is the rotational speed of the wind turbine as sensed by the RPM sensor, and C1, C2, C3, and C4 are constants. The constants C1, C2, C3, and C4 should be calculated for the specific wind turbine design to provide optimized output. In the preferred embodiment, the values of the constants are 0.0019, -0.11, 0.55, and 78 respectively. These values were determined empirically by trial and error using various values of the constants at a given wind speed until the output of the wind turbine was maximized. When the wind turbine is operating in Region 2, the duty cycle is continually calculated using Equation 1. If the duty cycle is higher than a predetermined

maximum duty cycle, then the duty cycle is simply set equal to the maximum value. The duty cycle varies from approximately 65% to 0% within Region 2 which extends from a rotor speed of approximately 500 RPM to an upper speed range that depends on battery voltage.

Region 3 is defined at its lower end by the point at which the duty cycle reaches 0% using the equation for Region 2. At its upper end, Region 3 is defined by the beginning of Region 4. The RPM range of Region 3 depends on the battery voltage. Within Region 3, the duty cycle of the FETs is 0%. Regions 2 and 3 together cover a wind speed range of approximately 10 mph to 40 mph.

Region 4 is above rated wind speed and, within this region, the controller applies a higher load on the alternator in order to increase the torque on the alternator to slow it. As the alternator slows, the blades enter aerodynamic stall and the power output from the wind turbine is reduced. Within Region 4, the duty cycle of the FETs is set to 65%. The controller continuously monitors the wind turbine's rotor speed and the battery bank's voltage level to determine when to enter Region 4. The equation that is used to determine when to enter Region 4 is:

$$RPM - C5 * V > C6 \qquad \text{Equation 2}$$

If the result of Equation 2 is true, then the controller increases the duty cycle to 65% to slow the rotor and induce aerodynamic stall. The constants C5 and C6 must be calculated for a particular wind turbine configuration. In the preferred embodiment, the value of C5 is 43 and the value of C6 is 840 so that the turbine enters stall at 1872 RPM for a nominal battery voltage of 24 V. The speed at which the turbine enters stall is dependent upon the charge state of the batteries so that it always enters stall at a constant power level. A

given rotor speed can correspond to varying power output levels depending on the charge level of the batteries. If a battery voltage other than 24 V is used, the values of C5 and C6 would have to be adjusted accordingly. For example, if a 48 V battery system were used, then the value of C5 would be 21.5 instead of 43. The value of C5 would also be different if the size or design of the wind turbine's blades is changed.

When the controller enters Region 4, a 15 second delay is implemented before the controller can switch to another operating region. This provides some time for the increased duty cycle to increase the alternator's reaction torque and slow the wind turbine's rotor before the operating parameters can be changed again. After the 15 second delay, the controller remains in Region 4 until the following equation is satisfied:

$$RPM - C7 * V < C8 \qquad \text{Equation 3}$$

If the result of the Equation 3 is true, then the controller returns to Region 3 and the duty cycle is set to 0%. The constants C7 and C8 must be calculated for a particular wind turbine configuration. In the preferred embodiment, the value of C7 is 21 and the value of C8 is -1 so that the turbine exits stall mode at 503 RPM for a nominal battery voltage of 24 V. The rotor speed, and corresponding power output, for exiting Region 4 are lower than the speed and power output at which the controller entered Region 4 so that there is some hysteresis. The equilibrium rotor speed with a duty cycle of 65% remains somewhere between 503 RPM and 750 RPM as long as the wind is above rated wind speed. The rotor will not slow down to a speed less than 503 RPM as long as the wind remains high. Therefore, the wind turbine will operate stably in a stalled condition at a reduced rotor speed and power output level as long as the wind speed remains above the rated wind speed.